LAND TRANSFORMATION AND POND SEDIMENT INFORMATION

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ABSTRACT

Five years of observations on sedimentation rates in two ponds located near transformed land areas in the Kobe district of central Japan have shown the relationship between sedimentation and development during land transformation. One of the ponds observed has artificial land transformation in its drainage area (KR), whereas the other does not (KN).

The sedimentation rate in the pond without artificial land transformation is roughly proportional to the rainfall intensity, whereas in the pond with land transformation it is related to change in the transformed area as well as the rainfall intensity. The relative sedimentation rate (sedimentation rate divided by the catchment area and rainfall intensity) is also related to loss on ignition and grain density; large relative sedimentation rates correspond to low loss on ignition and high grain density, suggesting that these factors are very sensitive to land transformation.

Changes in catchment factors, which indicate the topographical and hydrological conditions in the catchment area, are inversely proportional to change in the ratio of the reclaimed to the natural area; this is indicative of change in the erodibility of the surface material in the catchment area. © 1997 by John Wiley & Son, Ltd.

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INTRODUCTION

Geomorphic changes, such as landslides and man-made land transformation, make a significant contribution to catchment sediment yield and have a marked influence on pond sedimentation. This implies that the analysis of pond sediments will provide significant information on the geomorphic processes in the contributing catchment. A number of studies have been undertaken to reconstruct past geomorphic conditions on the basis of pond sediments (e.g. Robinson and Blyth, 1982; Foster *et al*., 1985, 1990; Kashiwaya *et al*., 1988, 1995). Environmental information on the impact of urbanization has also been obtained by analysing lake sediments (e.g. Foster *et al*., 1991; Charlesworth and Foster, 1993).

Lake sediments have been widely used to reveal past environmental changes caused by both natural and artificial events. It is difficult, however, to monitor current geomorphic changes using pond sediments of short time interval because such changes, in general, cannot be controlled and predicted except by direct experimentation. It is very important, however, to correlate the geomorphic phenomenon in progress with the sediments accumulating in ponds in order to show the erosion, transportation and sedimentation processes in ponds as well as in the contributing catchments.

The results analysed for pond sediments sampled sequentially through time with sediment traps are discussed and are related to the artificial geomorphic changes which occurred in the contributing catchment area.

STUDY AREA

Two ponds were chosen as survey sites in western Kobe, central Japan (Figure 1); one of the catchments has been under reclamation (KR-pond), and the other has had no reclamation (KN-pond). These are tributary ponds

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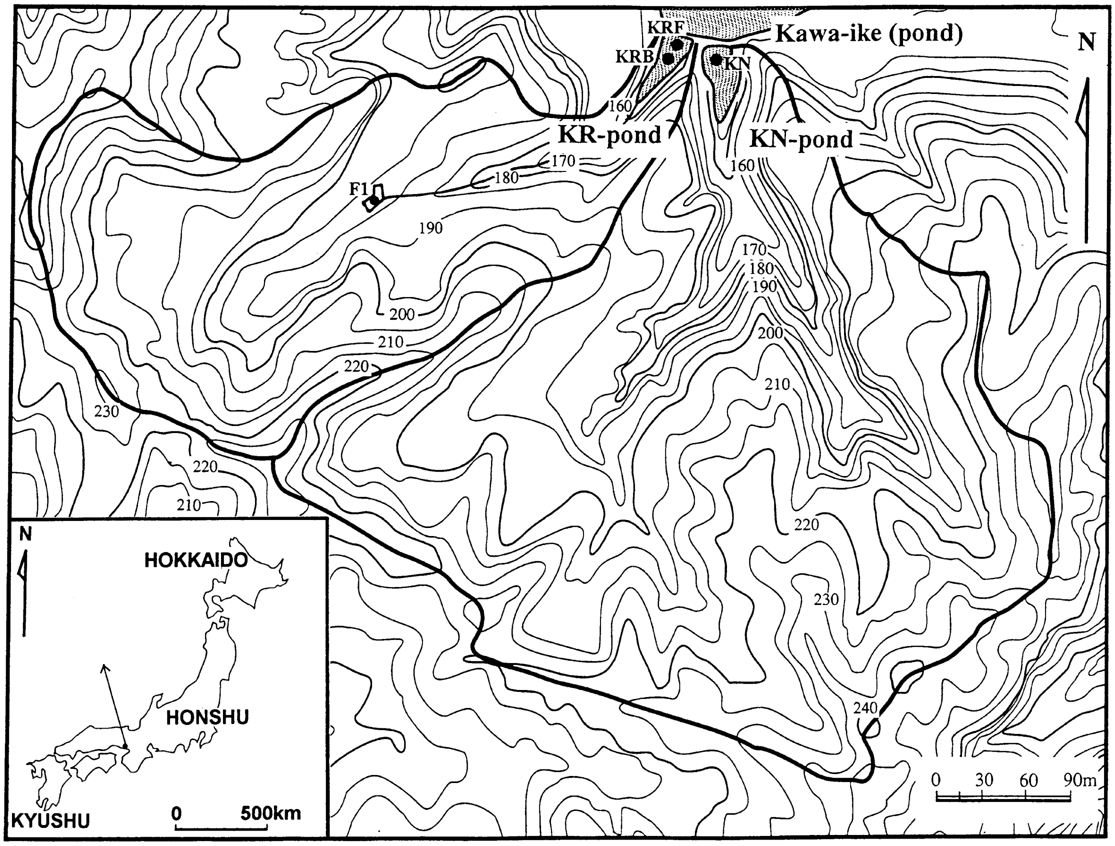


Figure 1. Area studied: •, sediment trap. Contour lines are in metres.

that drain into a major pond (Kawaike pond) through small flumes and they are connected to each other by a small pipe at the lower end of the ponds. They are used for irrigation during the summer (from March to October) and are drained dry during the winter. The two catchments are forested except for an area of reclamation. Part of the catchment area of KR-pond has been reclaimed to create industrial space.

The catchment area of KN-pond remains constant (19·0 ha), whereas the catchment area of KR-pond has changed due to reclamation. The size and conditions of the catchment area markedly affect surface erosion and subsequent sedimentation. In the KR-pond catchment area, the area as well as the ratio of natural slope to transformed (bare) slope have changed with the development of land transformation. Figure 2 shows the approximate change in catchment area and the ratio of the natural to the bare slope. The data indicate that transformation increased rapidly during 1990 and 1991 and decreased thereafter. Some small reservoirs were constructed to trap sediment in the area in 1991, and overflow water from the end reservoir (F1, constructed at the beginning of the reclamation) is drained into KR-pond. At present, the catchment area encompasses about 6·0 ha. The reclamation area was initially bare slope but gradually revegetated with plant growth and repairs (see Figure 11).

The geology around the catchment areas is mainly the Kobe group (sandstone, tuff, conglomerate and mudstone) of Miocene age and partially the Lower Osaka group (non-marine clay, sand, gravel, volcanic ash) of Pliocene age (Huzita *et al*., 1971). The initial catchment areas and relative relief for KR- and KN-ponds are 10·4 ha, 91 m and 19·0 ha, 87 m, respectively, and the average water surface areas during summer are 0·097 ha and 0·136 ha. There is some odour due to organic substances in KN-pond in summer. KR-pond has been influenced directly by land transformation, whereas KN-pond has been little changed and is more natural.

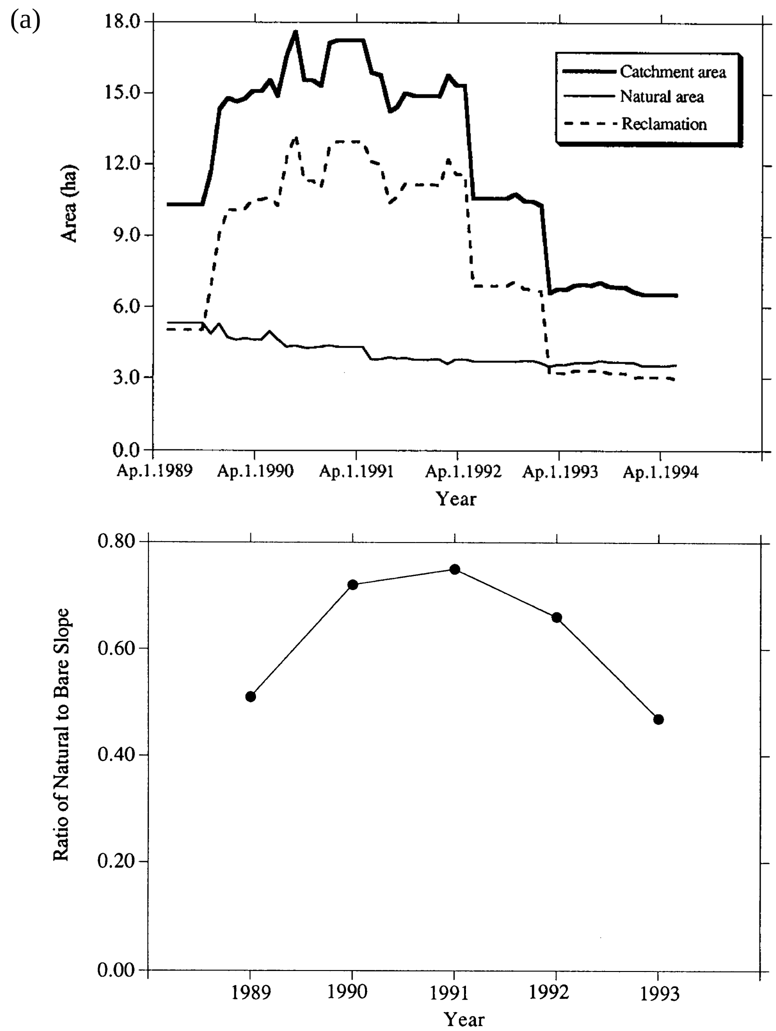


Figure 2. Changes in (a) the catchment area and (b) the ratio of the natural to the bare slope in KR pond.

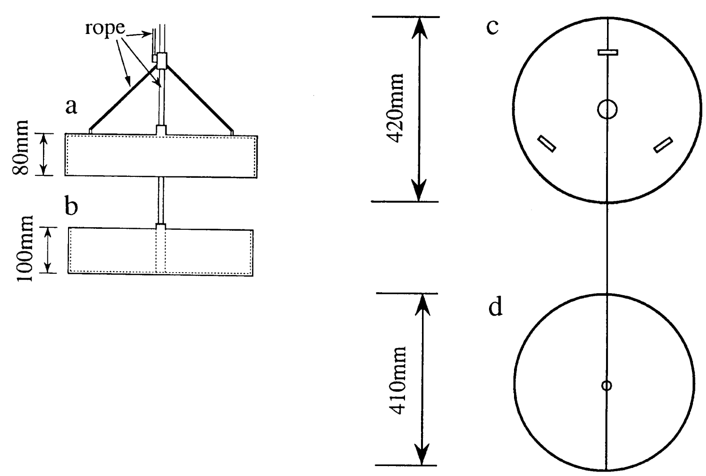


Figure 3. Sediment trap used for measurement: (a) sectional plan of the cover; (b) sectional plan of the trap; (c) plan figure of the cover; and (d) plan figure of the trap (after Kashiwaya *et al.*, 1995).

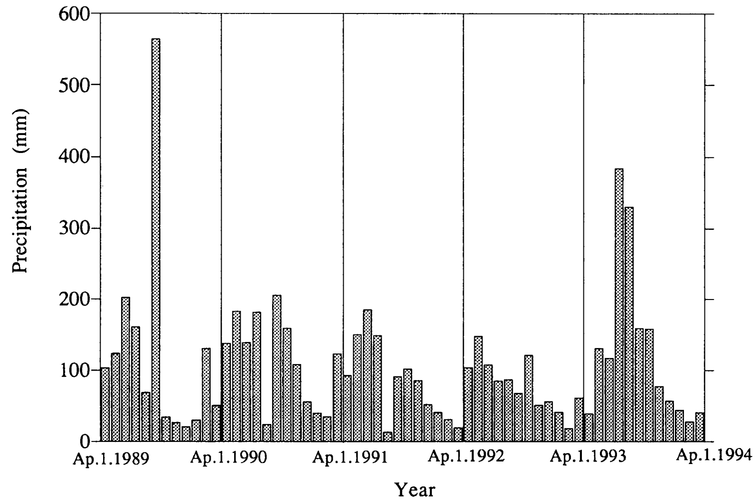


Figure 4. Monthly precipitation over a 5-year period.

MEASUREMENT AND SAMPLING

Precipitation was measured with a tipping-bucket raingauge at the side of KN-pond and the water level of KR-pond was measured with a floating type water level gauge. The water level in KN-pond is almost the same as in KR-pond. Pond sediments were sampled with sediment traps once a month in 1989 and 1990 and twice a month in 1991, 1992 and 1993.

Sediment traps were set on small concrete squares resting on the pond bed (Figure 3); two traps were located in the middle and lower parts of the KR-pond and one in the lower part of KN-pond. These were set roughly in the centre of flow so as to respond sensitively to changes in the sediment discharge from the catchments. Sediments were sampled during the summer season. A reference sediment trap was also set in the reservoir in the reclamation area (F1).

Pond bed morphology was measured after the annual water level lowering, by the use of equally spaced piles set on the bed and triangulation resurvey.

RESULTS

Precipitation

Precipitation is closely related to surface erosion and sediment transport, especially in bare areas under reclamation. Monthly precipitation over a five-year period is shown in Figure 4. The first month of the year is April because it was the time for water storage and trap setting. Generally, there is much rainfall in the rainy season (June and July) and in the typhoon season (September), with only a small amount of rainfall in winter. The situation was somewhat different in 1993, which was one of the coolest summers in the past 100 years (leading to a very poor rice harvest). Annual precipitation was very high in 1989 and 1993, and there was an especially large amount of rainfall (about 600 mm) in September 1989.

Sedimentation rate

The monthly sedimentation rate, M_m(g/month), is defined as:

$$M_m = (M_t/t) \times 30 \quad (1)$$

where M_t is sediment mass (g) and t the sampling interval (days). The sedimentation rate per unit catchment area needed to cancel the size effect of the area is discussed, but the storage effect in the catchment area due to the catchment conditions (size, slope, valley etc.) is not. That is, this sedimentation rate does not necessarily

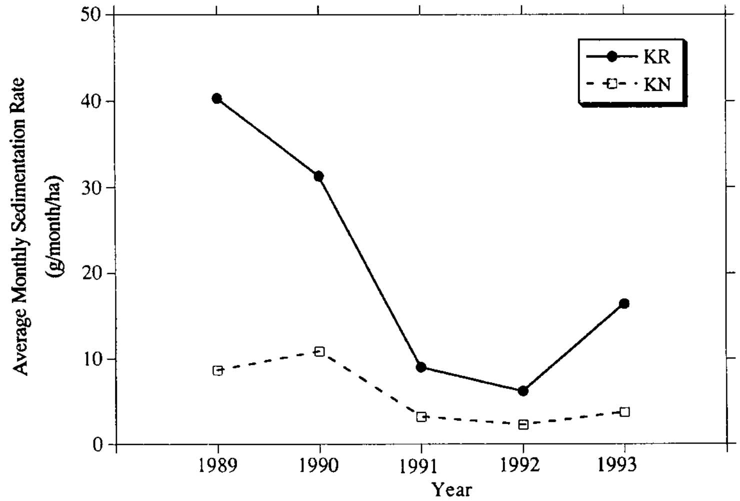


Figure 5. Average monthly sedimentation rate over a 5-year period (solid line, KR; broken line, KN).

indicate the erodibility of the surface material in the catchment area, as discussed later. Data from the sediment trap in the lower part of the KR-pond were used because they do not markedly differ from data from the other trap. The average monthly sedimentation rate for each year, shown in Figure 5, indicates that there is a distinct difference between the amount of sediment trapped in KR- and KN-ponds, in particular during the early stage of reclamation (1989 and 1990; reclamation for this area began in 1989). The slight similarity in the patterns exhibited by both curves may be due to the fact that the rainfall conditions were the same and that the ponds are connected in their lower parts by a pipe, as mentioned. Hydrological conditions in both catchments are similar. It should also be noted that this sedimentation rate does not represent the average sedimentation rate, but that of the most sensitive areas of the ponds.

Grain size

Grain size parameters in the centre of the ponds are mainly controlled by bed transport processes, but the slope and fluvial processes in the catchments also influence them. Figure 6 shows changes in the grain size parameters (median and standard deviation). Median values for both ponds range from 9 to 10 ϕ with no conspicuous difference, particularly for 1991–1993, when the sedimentation rates are small for both ponds. In the periods when there was a comparatively high sedimentation rate (1989–1990), more sorted fine sediments flowed into KR-pond, perhaps as a result of large overflow from the upper reservoir (F1).

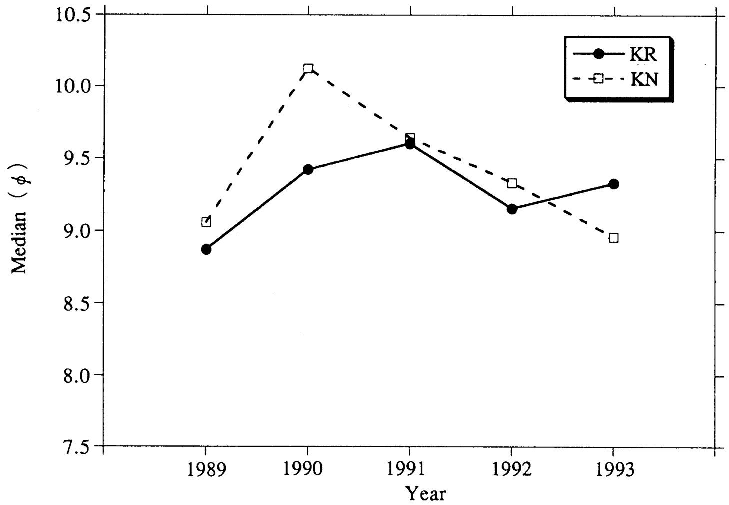
Grain density

Grain density is controlled by its components and, probably, is closely related to organic matter content. Analytical results for each pond, given in Figure 7, show fairly high values in KR-pond with the reclamation area, indicative of comparatively large amounts of material from the reclamation area with low organic-matter content. The values increase initially, but they have decreased since 1991, suggesting that they have responded to the changing conditions in the reclamation area.

Loss on ignition

Measurement of loss on ignition was used to check the inference that the organic matter content in sediment from the reclamation area (bare area) is lower than that in sediment from natural slopes. Loss on ignition for sediment from the reservoir in the reclamation area (F1) was also measured as a reference. The average yearly loss on ignition for each pond is given in Figure 8. As suggested above, the loss on ignition values for sediment in the reclamation area (F1) are lowest and those for the catchment without a reclamation area (KN) are highest.

(a)



(b)

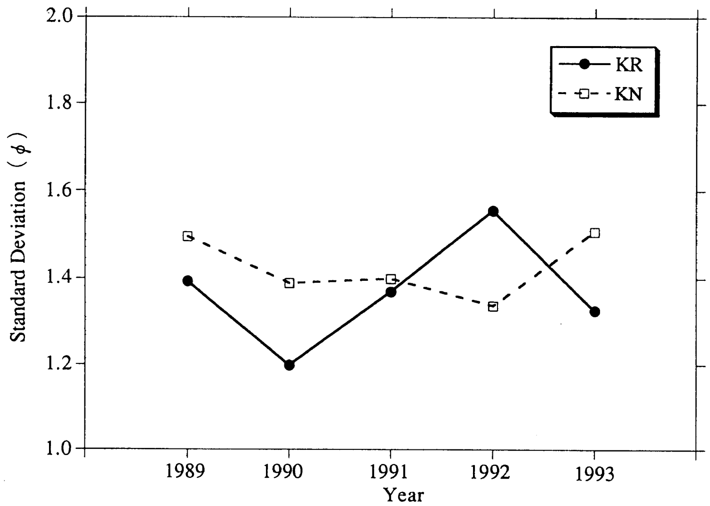


Figure 6. Changes in grain size parameters (solid line, KR; broken line, KN): (a) median and (b) standard deviation.

The trends in loss on ignition for KR- and KN-ponds are inversely related to those for grain density, which supports the inference that grain density is markedly affected by the amount of organic matter.

DISCUSSION

Sedimentation in ponds is mainly related to three factors: the field conditions under which sediment material is produced (conditions of the catchment area such as slope, valley density, hollow, etc.); erosional conditions (rainfall intensity); and internal pond conditions (water level, bed morphology, etc.). These relationships are expressed approximately as:

$$M(t) = P_f(t) \times C_f(t) \times R_f(t) \qquad (2)$$

where $M(t)$ is the sedimentation rate, $P_f(t)$ the pond factor, $C_f(t)$ the catchment area factor, and $R_f(t)$ the rainfall factor. When pond conditions do not change markedly (e.g. bank collapse), Equation 2 becomes:

$$M(t) \propto C_f(t) \times R_f(t) \qquad (3)$$

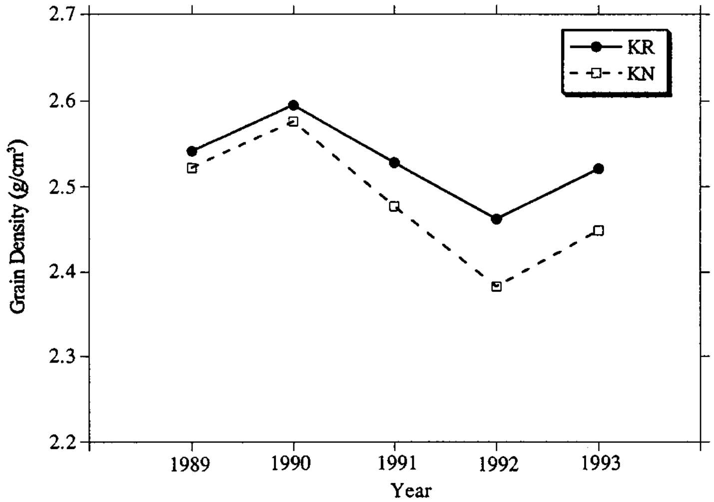


Figure 7. Changes in average grain density (solid line, KR; broken line, KN).

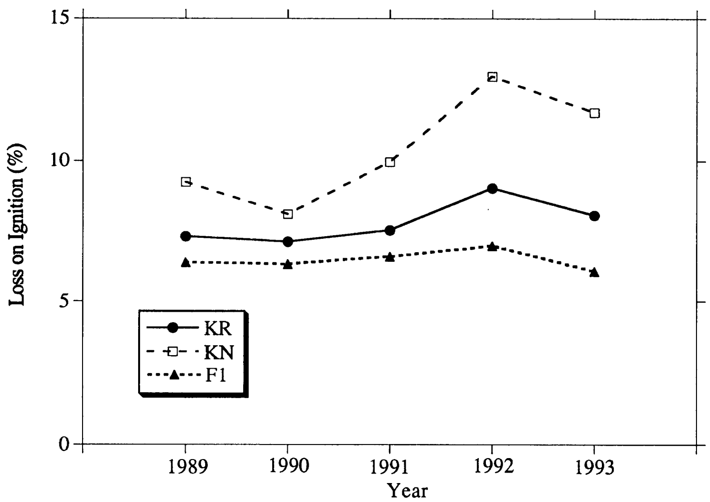
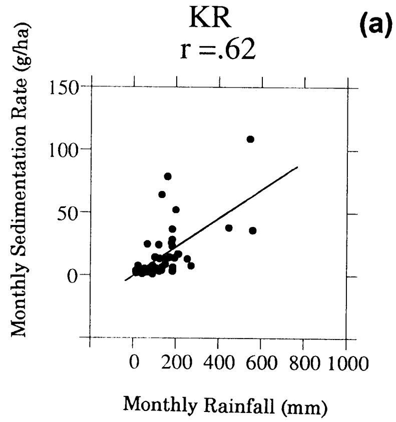


Figure 8. Average yearly loss on ignition.

To check the relationship between sedimentation rate and rainfall intensity, the monthly sedimentation rate (the sedimentation rates derived above are considered representative values for each pond) and monthly rainfall (defined for the same time interval as the monthly sedimentation rate) was used. Results, shown in Figure 9, indicate that the sedimentation rate is roughly proportional to the rainfall intensity. This suggests that the poor correlation between the two sites may be mainly due to the catchment factor. If the pond factor, $P_f(t)$, is regarded as constant, Equation 2 is modified to:

$$C_f(t) \propto M(t)/R_f(t) \tag{4}$$

This shows that the erodibility of catchment surface material is expressed as a relative catchment factor, $M(t)/R_f(t)$. Average yearly values for $M(t)/R_f(t)$ are shown in Figure 10. Values for the KR sediment are much larger than those for KN, which suggests that sediment produced in the catchment area moves more easily into the pond in the KR catchment area than in the KN area. This relative catchment factor shows clearly the difference in catchment conditions between KR and KN.



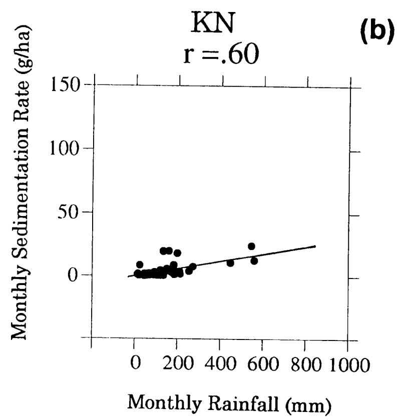


Figure 9. Sedimentation rate and rainfall intensity for (a) the KR-pond and (b) the KN-pond. r is the correlation coefficient.

The values for KR increase at the earliest stage with the progress of the reclamation, but they rapidly become low from 1991 onwards. As noted before, this is because of the completion of reservoirs to reduce sediment discharge in the KR-catchment area – another artificial modification of the catchment factor – though it may be partly related to plant growth and repairs to the reclamation area (Figure 11). A slight similarity in the pattern of the curves is, as mentioned earlier, due to the fact that catchment areas experience similar hydrological conditions and they are connected by a pipe; some sediment from the reclamation area might flow into the KN-pond at times of high discharge.

Comparison of Figure 10 with Figures 7 and 8 shows that the values for $M(t)/R_f(t)$ are roughly related to changes in loss on ignition and grain density; values for loss on ignition are inversely related to those for $M(t)/R_f(t)$ while grain density values are positively related to $M(t)/R_f(t)$. As shown in the previous sections, there is a distinct difference between KR and KN in the values for loss on ignition and grain density, which suggests that they reflect differences in catchment conditions; the loss on ignition and grain density may be used to evaluate the catchment factor.

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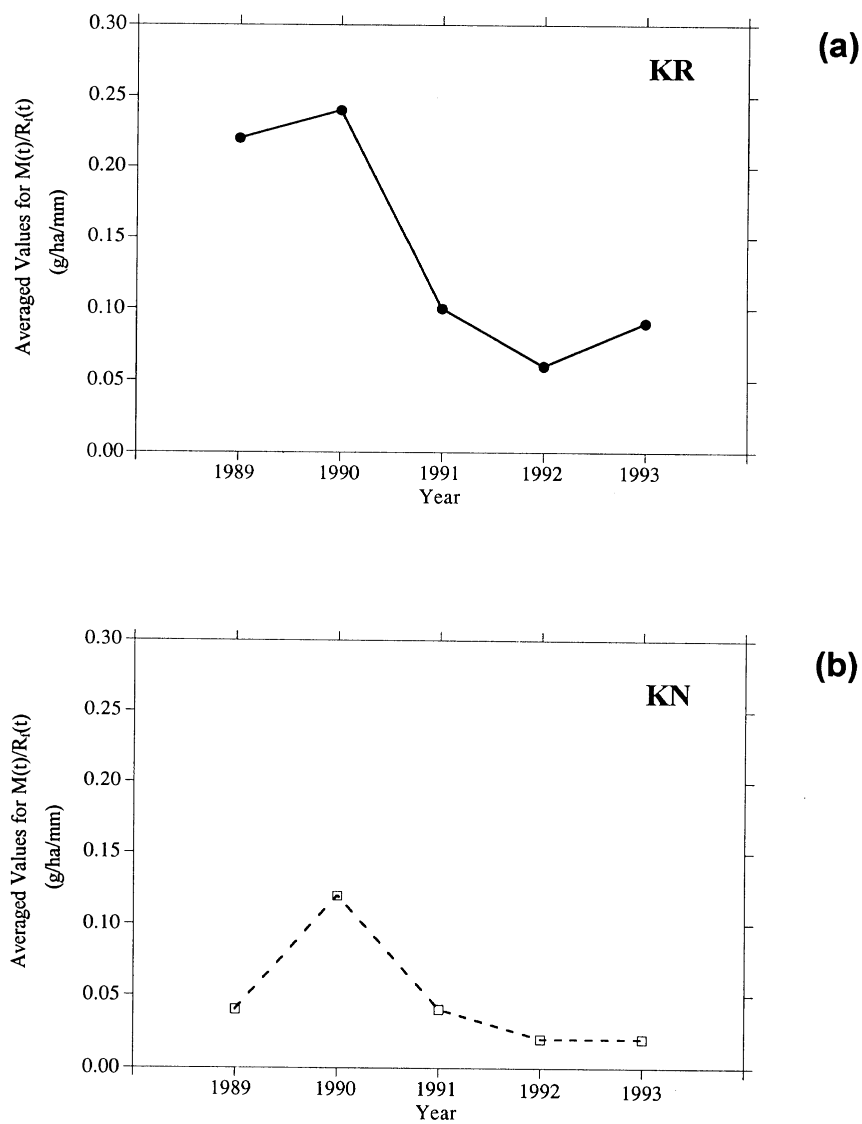

Figure 10. Changes in the catchment factor, $M(t)/R/(t)$; (a) KR and (b) KN.

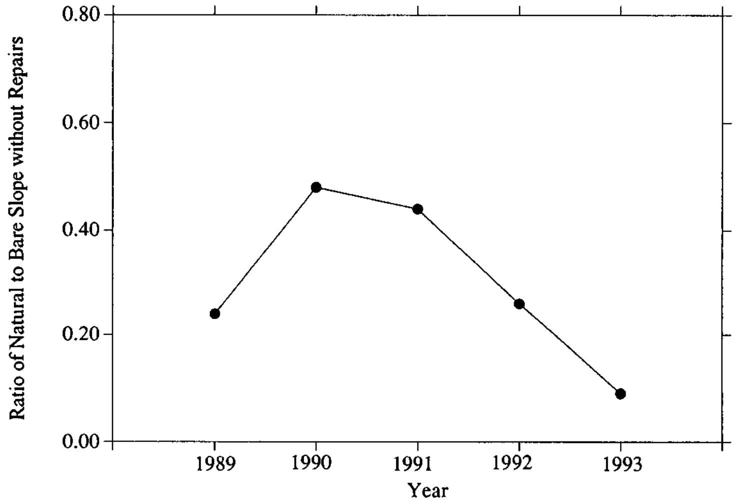

Figure 11. Changes in the ratio of the natural to the bare slope without plant growth and repairs in the KR-pond catchment.

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